

THE INSULT OF A FOREIGN BODY

Samuel G. Steinemann

Straumann Institute, Waldenburg, & University of Lausanne, Switzerland.

In living tissue, a surgical implant is a foreign body, which interacts in various manners with its environment. This foreign body can be an insult to life (using a wording of psychiatrist Sigmund Freud in *Imago*, Bd. 5, 1917) of chemical, physiological or mechanical kind. In fact, this metal implant is not like living tissue, where no free electrons exist and where metals, such as essential trace elements, occur in a bound and not in an elemental state. Any of these interactions between life processes and the implant, i.e. the foreign body, is connected with specific phenomena and a typical length. The bone structure and also for some soft tissue is dependent upon the mechanical environment; these tissues have typical lengths of mm (trabeculae, osteons). Physiological processes, in particular tissue growth, depend upon cells, which have a typical size of micrometers; transport processes in the tissue electrolyte become important. Chemical and physical processes occur in the nanometer range of lengths; over such distances (up to 20nm) can occur the charge transfers of electrons and protons. Adhesion is an example for such processes.

Many laws of biomechanics are known, e.g. for the bending stiffness and bending breaking strength of bone, also Young's modulus and the compressive strength. The question is though: Are the laws of men for prosthetic devices as good as the laws of nature? Three propositions are given: (i) the stiffness of the implant (dental case) should be approximately that for bone, (ii) isoelastic behaviour towards the bone guarantees good load transfer, and (iii) the device should guide and distribute forces and to perform this it must be stiff. Different concepts become apparent, are they wrong or right? Stiffness is the product of two quantities, Young's modulus and the moment of inertia, which varies strongly with size. Young's modulus also varies strongly with the material; the ratio for modulus of material/modulus of bone is 20 for sapphire (Kawahara dental implant), 10 for the cobalt alloy and 5 for titanium (Ti). Material and design of the prosthetic device must match.

Maurer et al (1993) studied cell proliferation (fibroblast, osteoblast) under different conditions: cells are exposed to a metal-saturated electrolyte and grow on an inert support or cells are inoculated and grow on a metal support. The results suggest that the metal-cell interaction has two modes, a weak interaction and a strong interaction. The dissolved metal produces no growth inhibition. Cells must be in contact with the solid metal; then, fibroblasts can proliferate on Ti, Nb, Zr, Ta and osteoblasts can

proliferate on Ti, Zr only. This result has high interest.

The connection between bond and implant is amenable to mechanical measurements. The bond can be quantified by push-out and release-torque tests. Their results however depend on surface roughness, i.e. geometry or structure, and may not reflect a functional connection such as adhesion. This latter property is obtained in pull-out tests. The forces to separate an implant from bone are equal to (tensile) strengths up to 3 MPa. This is a high load, which exceeds by orders of magnitude a physical adhesion mechanism such as breaking a vacuum or rupturing Van der Waal's intermolecular bonds. Certainly, there can be no empty space or free water present at the interface. Thus, one may ask: what is the glue? The functional connection, i.e. osseointegration, must hide a chemical origin. Ti is a reactive metal. This means that in air or any aqueous electrolyte, an oxide is spontaneously formed on the metal. Further, as Boehm shows in a classical study, this surface oxide is hydroxylated and has amphoteric, or bipolar character. The chemisorption ability of such surfaces is well known. In particular, peptides and amino acids act as ligands and attach to Ti oxide by replacement of the surface hydroxyl. The kind of bond, however, needs to be specified. A study using X-ray excited photoelectron diffraction of glycine adsorbed on single-crystal rutile shows correct distances and angles among carbon and nitrogen atoms on top of the oxide and this is sufficient evidence for covalent bonding between the amino acid and the (foreign body) oxide. The result of the photoelectron diffraction experiment suggests considering osseointegration on a same footing as peptide formation, i.e. as a condensation reaction. The terminal carboxyl and amino groups of amino acids and proteins bind with the surface hydroxyls. The connecting links of the surface complexes come out to be pieces of the peptide bond, i.e. $-(C=O)-$ and $-(N-H)-$. Bone adhesion happens in new dimensions.

References :S.G. Steinemann in *Titanium Science and Technology* (Eds.: G. Lütjering, U. Zwicker, W. Bunk), Deutsche Gesellschaft Metallkunde, Oberursel 1985, 1373-1379. A.M. Maurer, V.D. Lê, S.G. Steinemann, H. Guenther, J. Bille, 10th Eur. Conf. Biomaterials, Davos, 1993. H.P. Boehm, *Disc. Faraday Soc.* 1971, 52, 264-275. L. Pattthey, PhD thesis University of Lausanne, 1995. S.G. Steinemann, *Euromat 99, Materials for Medical Engineering* (H. Stallforth, P. Revell, eds.)